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Impact of window selection on the energy performance of residential buildings in South Korea

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ABSTRACT

With rapidly increasing energy consumption attributed to residential buildings in South Korea, there is a need to update requirements of the building energy code in order to improve the energy performance of buildings. This paper provides some guidelines to improve the building energy code to better select glazing types that minimize total energy use of residential buildings in Korea. In particular, detailed energy simulation analyses coupled with economical and environmental assessments are carried out to assess the thermal, economical, and environmental impacts of glazing thermal characteristics as well as window sizes associated with housing units in various representative climates within South Korea. The results of the analyses have clearly indicated that selecting glazing with low solar heat gain coefficient is highly beneficial especially for large windows and for mild climates. In particular, it is found that using any double-pane low-e glazing would provide better performance for windows in residential buildings than the clear double-pane glazing, currently required by the Korean building energy code.

1. Introduction

In South Korea, 24% (i.e., 1.62 quads, 1.7 EJ) of the total national energy consumption (about 6.78 quads, 7.15 EJ) is used by the building section. In particular, residential buildings consume more than 55% (i.e., 0.92 quads, 0.97 EJ) of the energy used in buildings in South Korea (KEEI, 2006). Windows contribute significantly to both heating and cooling energy consumption of residential buildings. Indeed, a study has estimated that almost 30% (or 0.11 quads, 0.12 EJ) of the total energy needed to condition residential buildings is attributable to heat transfer through windows (Yoo et al., 2005).

The existing building energy code of South Korea requires threshold thermal performance for specific building envelope components (including exterior walls, roofs, floors, interior walls, windows, and doors) for three climatic zones (Central, Southern, and Cheju Island) as illustrated in Fig. 1. The current Korean energy efficiency code is applicable to any building type including commercial, residential, or mixed-use buildings. For windows, the code specifies *U*-factor requirements for the combined glazing and framing using a total window *U*-value. In particular, the current code requirements for total window *U*-values are 0.52 Btu/h ft^2 °F (3.0 W/m^2 K) for the central regions, 0.58 Btu/h ft^2 °F (3.3 W/m^2 K) for the southern regions, and 0.74 Btu/h ft^2 °F (4.2 W/m^2 K) for the Cheju Island region. In the future, the South Korean government plans to develop a building energy code specific to residential buildings and may impose the use of low-e and triple glazing.

For any building, windows can provide visual amenity to occupants and improve esthetic and good appearance to the building exterior. In terms of thermal impact, windows can either decrease or increase space heating loads through solar heat gains or conduction heat losses, respectively. In South Korea, several newly constructed buildings are characterized by large windows and high window to wall ratios. In order to reduce the thermal impact of these large windows, there is a tendency to use low-e glazing for new constructions. Low-e glazing with high solar heat gain coefficient is suitable for the heating dominated climates. However, glazing with low heat gain coefficient is desirable for cooling dominated climates.

Several studies have been reported to help designers select suitable window systems for buildings. A study by Apte et al. (2003) indicated that low-e windows typically saved about 40% of building energy use attributable to windows in most US climates. The same study found that dynamic and ultra-efficient windows (with a *U*-factor of about 0.10 Btu/h ft^2 °F (0.57 W/m^2 K)) and SHGC of 0.10–0.35 technologies can use as little or less energy than a home with no windows. In particular, dynamic windows, with solar heat gain properties that vary with the season, are

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Fig. 1. Climate zones in South Korea.

found to offer significant potential in reducing peak demands in northern and central US climates, while static windows with very low solar heat gain properties offer the most potential in southern climates. Another study by Arasteh et al. (2007) found that in heating-dominated climates such as Minneapolis, Salt Lake City, and Washington D.C., windows with a *U*-factor of 0.10 Btu/h ft^2 °F (0.57 W/m^2 K) can be energy neutral with solar heat gains offsetting conductive losses during the winter. It is also found that dynamic windows, with the ability to modulate solar heat gain coefficient from a high value during the heating season to a low value during the cooling season, can be net energy producers in mixed climates with both heating and cooling seasons. A life cycle assessment analysis of an advanced window system found that an electro-chromic glazing can be suitable for cooling dominated climates with a potential of providing 55% of energy savings (Papaefthimiou et al., 2009). Singh and Garg (2009) carried out a detailed energy analysis to develop an energy rating model to select window glazing for buildings in India. Ten different window systems, including single clear glazing and double low-e, absorbing film coated and reflective film coated glazing, were considered in the analysis. The results of the energy analysis indicated that a double reflective film coated glazing achieved 17–22% energy savings in cooling dominated regions but 13–27% energy increases in heating dominated regions. Double low-e coated glazing was recommended to reduce building energy use in cold climates. The effect of solar energy transmittance through the rooms in residential buildings in Iran has been investigated for selected combinations of glazing systems and overhang configurations (Ebrahimpour and Maerefat, 2011). The results of the study indicated that single clear pane glazing with overhangs or side fins lead to the reduction of building energy use equivalent to high performance glazing. However, double low-e glazing window was found to be the most energy efficient option. Gasparella et al. (2011) have evaluated the impact of glazing systems and window sizes on thermal performance of well insulated residential buildings in central and southern European climates. They concluded that triple glazing provides the best energy performance. Moreover, they found that windows with low thermal transmittance would reduce building energy use in wintertime but would increase energy consumption during summertime.

For South Korean residential buildings, Leigh and Won (2004) found that the impact of the glazing type on cooling loads is rather small, but significant on heating loads. For instance, the heating load of a south-oriented house with double low-e glazing is half that of a south-oriented house with single glazing. Based on the results of their analysis, Leigh et al. suggest using low-e glazing to achieve both heating and cooling energy savings. Similar studies were conducted by Kim et al. (2004) and Mun et al. (2007) to evaluate thermal performance of low-e glazing for office buildings. In particular, Kim et al. have suggested the use of clear low-e glazing in mixed heating and cooling climates and tinted low-e glazing in cooling dominated climates.

In this paper, the results of a detailed analysis are described to evaluate the impact of thermal properties of glazing on both heating and cooling of prototypical residential unit in various South Korean climates and window distributions. General guidelines are then developed to help designers select the proper glazing for residential buildings in order to minimize the energy impact of windows. First, the energy analysis approach is described. Then, a summary of the analysis results is provided.

2. Analysis approach

To analyze energy performance of various window glazing types, features of a prototypical housing unit such as floor area, orientation, window-to-wall ratio (WWR), and aspect ratio were defined using results from previously published surveys and studies. According to a survey of residential buildings in South Korea, the average housing unit have an area of 1076 ft^2 (100 m^2), an aspect ratio of 1:1.2, and 1-story south-ward orientation (Jang et al., 2004). The average WWRs for each orientation are 45% in the South, 15% in the North, 10% in the East, and 10% in the West (Kim et al., 2001) while the lighting power density (LPD) is 1.21 W/ft^2 (13 W/m^2) (Leigh and Won, 2004). Tables 1 and 2 summarize the basic features of the prototypical housing unit used in the energy analysis. As indicated in Table 1, a gas furnace is used for heating (efficiency=80.6%) and DX coil (COP 2.86) is used for cooling. The thermostat set-point for heating is 68 °F (20 °C) and for cooling is 82.4 °F (28 °C). Table 2 lists the thermal characteristics of the building envelope and the values in parenthesis presents the guidelines based on the Korea energy efficiency code.

The housing unit features outlined in Tables 1 and 2 are used to model the prototypical unit using DOE-2 (Winkelmann et al., 1993), a detailed hourly building energy simulation tool. In the simulation analysis, the size and the glazing properties are varied to model various potential window configurations for the prototypical housing unit. In particular, WWR is varied from 10 to 30% with 10% increment. The glazing thermal properties including SHGC and *U*-factor are varied from 0 to 1 with 0.1 increments so a total of 300 window configurations are considered for each climate. Two cities Inchon and Ulsan are selected to represent

Table 1
Characteristics of a prototypical housing unit in South Korea.

Parameter	**Value**
Floor area	1076 ft^2 (100 m^2)
Aspect ratio	1:1.2
House construction	New construction (one story)
Foundation	Slab-on-grade
Fenestration type	User defined
Fenestration distribution	20% of each wall area, equally distributed on all four orientations
Solar gain reduction	0.7 ft (0.2 m) overhang
Insulation	Envelope insulation levels are based on location of the envelope (See Table 3)
Infiltration	0.6 ACH
Internal mass furniture	8 lb/ft^2 (39 kg/m^2)
HVAC system	Gas furnace and electric DX coil air conditioner
HVAC efficiency	DX coil air conditioner: COP 2.86, furnace efficiency: 80.6%
Part-load performance	Part-load curves of DOE-2
Thermostat settings	Heating: 68 °F (20 °C), cooling: 82.4 °F (28 °C)
Internal loads	4 people, lighting: 1.21 W/ft^2 (13 W/m^2), equipment: 0.47 W/ft^2 (5 W/m^2)

Table 2
U-values for building envelope components for the prototypical housing unit.

Parameters	Inchon		Ulsan	
	Btu/h ft^2 °F	W/m^2 K	Btu/h ft^2 °F	W/m^2 K
Exterior walls	0.076 (0.083)	0.43 (0.47)	0.093 (0.102)	0.53 (0.58)
Roof	0.045 (0.051)	0.26 (0.29)	0.058 (0.062)	0.33 (0.35)
Floor	0.047 (0.062)	0.27 (0.35)	0.053 (0.072)	0.30 (0.41)
Windows	0.540 (0.676)	3.07 (3.84)	0.540 (0.738)	3.07 (4.19)

the central region climate and southern region climate, respectively. Similar to most regions in South Korea, both cities have heating dominated features but Ulsan is milder during the winter. Table 3 provides the heating degree days (HDD) and cooling degree days (CDD) for both representative cities.

Table 4 lists SHGC and *U*-factor values for six specific window glazing types. Specifically, window glazing #2 is selected since it is a commonly used glazing type in South Korean residential houses. Window glazing #3 is a standard low-e glass with *U*-factor=0.41 Btu/h ft^2 °F (2.33 W/m^2 K) and SHGC=0.52. Window glazing #4, with *U*-factor=0.31 Btu/h ft^2 °F (1.76 W/m^2 K) and SHGC=0.25, is selected to estimate potential energy savings when a better alternative to glazing #3 is used. Window glazing #5, with *U*-factor=0.29 Btu/h ft^2 °F (1.64 W/m^2 K) and SHGC=0.59, has low *U*-factor but higher SHGC than glazing #4 but has lower SHGC than glazing #3. *U*-factor is the smallest among double low-e glazing. Finally, window glazing types #1 and #6 are considered to represent, respectively, the worst and best glazing types in terms of energy performance.

The energy simulation analysis considers the impact of first the size and the distribution of the windows and then the thermal properties of the glazing type. The window size is modeled by varying WWR from 10% [i.e., window area of south and north wall is 35.2 ft^2 (3.3 m^2) and that of east and west is 29.3 ft^2 (2.7 m^2)], 20% [i.e., window area of south and north is 70.4 ft^2 (6.6 m^2), and that of east and west is 58.6 ft^2 (5.4 m^2)], and 30% [i.e., window area of south and north is 105.6 ft^2 (9.9 m^2), and that of east and west is 88.0 ft^2 (8.2 m^2)] using a uniform window distribution regardless of wall orientation as shown in Fig. 2. A non-uniform window distribution is also considered in the analysis with WWR varying with window orientation according to survey data as illustrated in Fig. 3 (Leigh and Won, 2004).

The simulation results for two cities are summarized for all window and glazing combinations and compared to those obtained for a windowless housing unit (i.e., WWR=0). The annual heating and cooling energy use are considered in the analysis. In order to

Table 3
Heating and cooling degree-days of two cities.

City	Heatingdegree-days		Coolingdegree-days	
	$HDD_{64.4\ °F}$ (°F)	$HDD_{18\ °C}$ (°C)	$CDD_{75.2\ °F}$ (°F)	$CDD_{24\ °C}$ (°C)
Inchon	5285	2936	108	60
Ulsan	4141	2300	232	129

Table 4
Properties of six window glazing types.

Glazing	*U*-factor		SHGC	Description
	Btu/h ft^2 °F	W/m^2 K		
#1	1.03	5.62	0.82	Single clear, vinyl frame
#2	0.54	3.07	0.70	Double clear, air, vinyl frame
#3	0.41	2.33	0.53	Double low-e clear, air, vinyl frame
#4	0.31	1.76	0.26	Double low-e green, air, vinyl frame
#5	0.29	1.64	0.60	Double low-e clear, argon, vinyl frame
#6	0.21	1.19	0.48	Triple low-e, air, vinyl frame

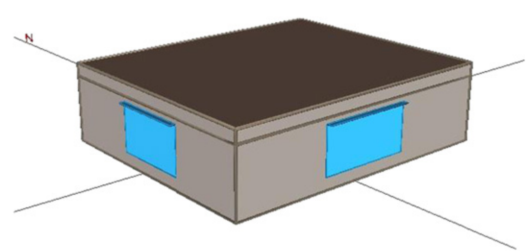

Fig. 2. 3D model for equal distribution windows.

obtain the combination of two energy end-uses, source energy is estimated using a multiplier of 3.0 for electrical energy use to represent the site to source efficiency (a typical power plant efficiency is South Korea is 33%).

3. Simulation results

Figs. 4 through 9 summarizes the impact of window glazing selection on annual total source energy use as well as total heating and cooling energy use for the prototypical housing unit

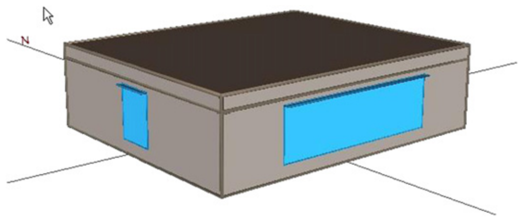

Fig. 3. 3D model for non-equal distribution windows.

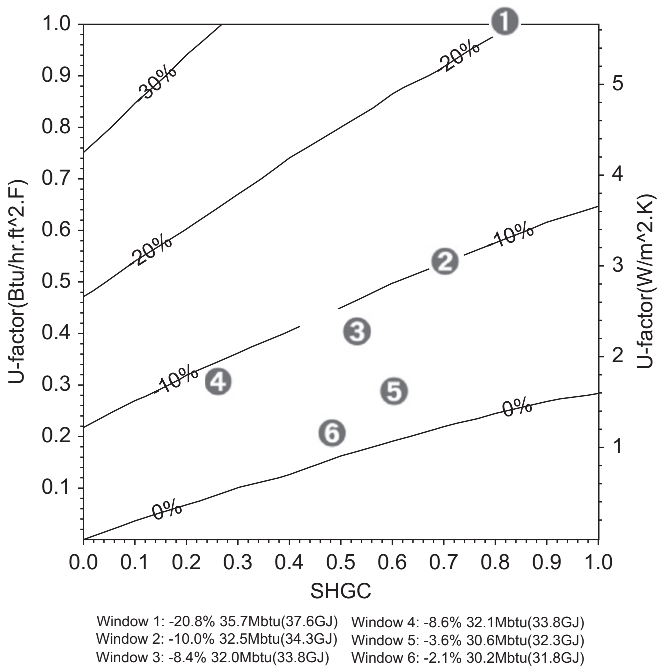

Fig. 4. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=10% and uniform window distribution located in Inchon.

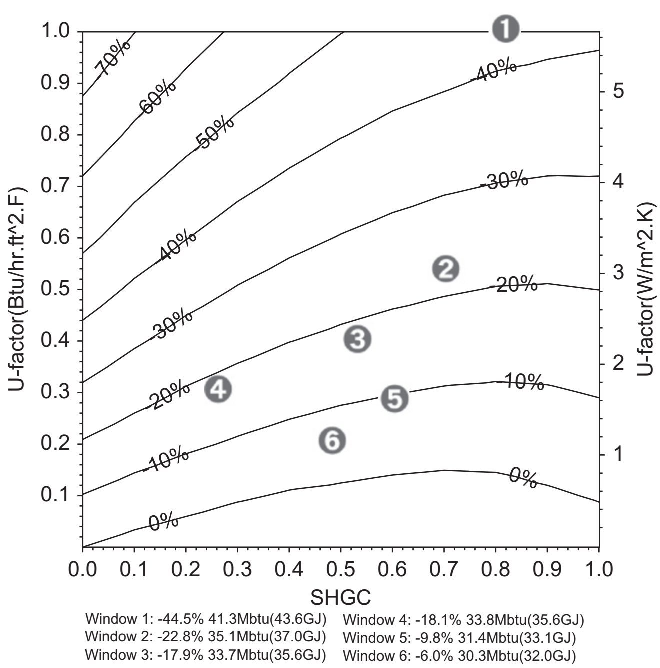

Fig. 5. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=20% and uniform window distribution located in Inchon.

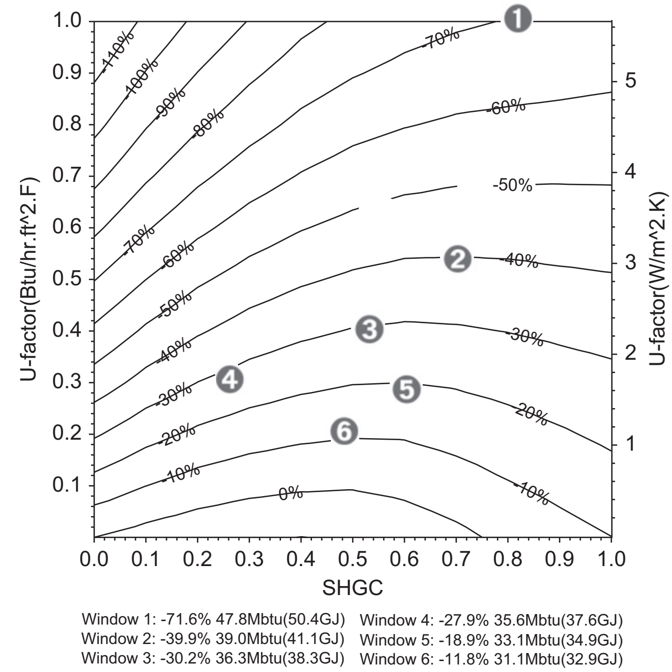

Fig. 6. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=30% and uniform window distribution located in Inchon.

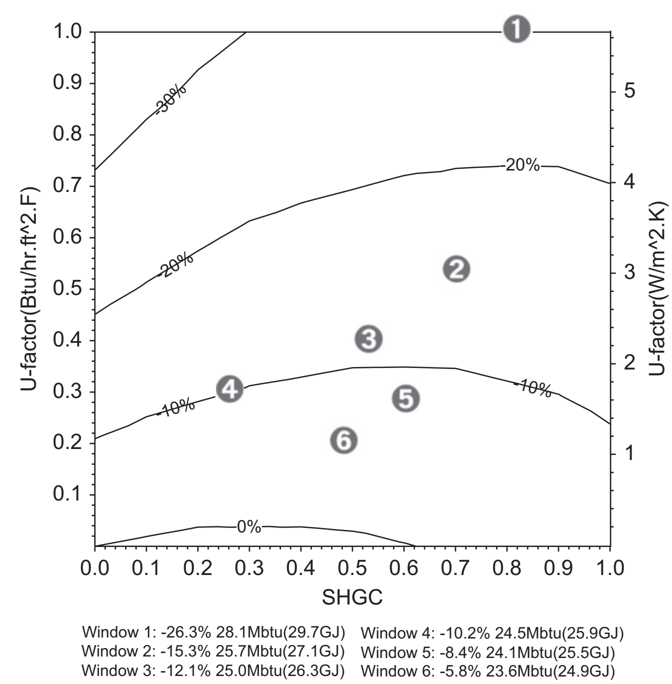

Fig. 7. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=10% and uniform window distribution located in Ulsan.

for two South Korean climates and three WWR values (10%, 20%, and 30%) when the windows are uniformly distributed along the four orientations as shown in Fig. 2. The results are expressed using the percentage reduction relative to the annual total source energy use obtained for the baseline case with an adiabatic and opaque windows (i.e., SHGC=0 and *U*-factor=0). In Figs. 4–9, the x and y axes represent variation of SHGC and *U*-factor, respectively, while the contour lines indicate the percentage reduction

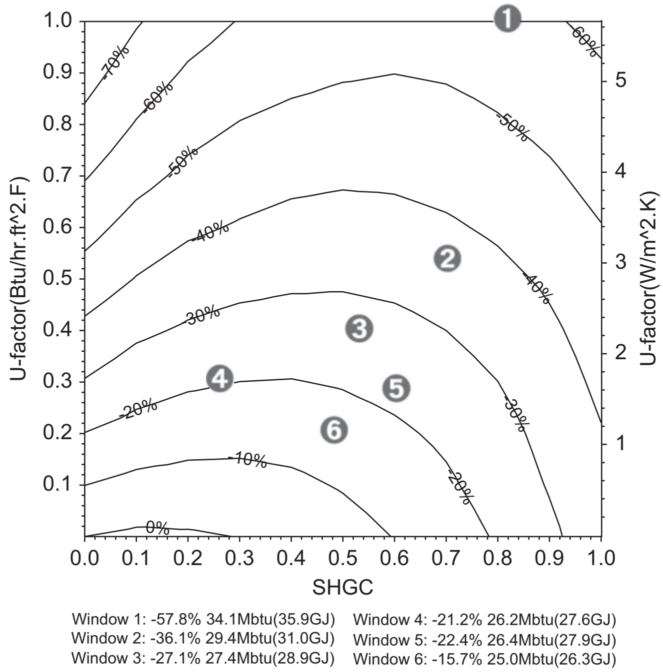

Fig. 8. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=20% and uniform window distribution located in Ulsan.

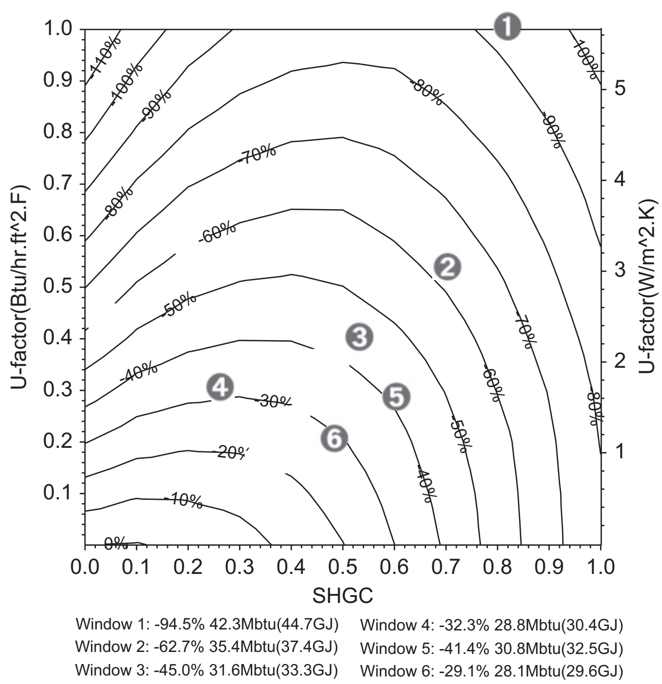

Fig. 9. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with WWR=30% and uniform window distribution located in Ulsan.

level. The performance of the six glazing types are also shown in Figs. 4 through 9 as identified by their number listed in Table 4.

The total source energy use for the baseline case housing unit that has no heat loss or solar heat gains through windows is estimated to be 27.9 MBtu (29.4 GJ) for Inchon and 21.8 MBtu (23.0 GJ) for Ulsan. Therefore, a positive percentage reduction indicates that the glazing leads to higher total source energy use by the housing unit. The zero percentage reduction contour line provides the glazing properties that lead to thermally neural windows performing as adiabatic and opaque windows. Negative percentage reduction translates the fact that the windows increase the overall energy consumption of the housing unit. As indicated by the results shown in Figs. 4 through 9, several observations can be made:

- The heating dominated climate of Inchon is more suitable than the milder climate of Ulsan to select windows with neutral impact. In fact, for the case when the housing unit has small windows (i.e., WWR=10%), glazing type #6 leads to only 3% increase in annual total housing unit source energy use when the housing unit is located in Inchon. However, the same glazing type results in 7% increase for the same housing unit and window size located in Ulsan.
- As the window size increases, the housing unit uses more total source energy independent of the glazing type selected. In fact, there is no glazing type that can reduce the energy use when WWR=30% especially when the housing unit is located in Ulsan.
- While as expected, glazing type #1 provides the highest increase in total energy use, glazing types #3 and 4 have similar thermal performance when the housing unit is located in Inchon independent of the window size. Glazing type #2, a commonly used glazing in South Korea, provides similar thermal performance than glazing types #3 and #4 when WWR=10% but is noticeably less effective for larger windows. For all considered climates and window sizes, glazing type #6 followed by glazing type #5 provide the best thermal performance.
- For the case of small windows (WWR=10%), glazing types with the same *U*-factor but increasing SHGC values results in lower annual total source energy use when the housing unit is located in the cold climate of Inchon. However, when the unit is located in the milder climate of Ulsan or when the windows are large (WWR=20% or 30%), higher SHGC values leads to higher energy use. This result indicates that an upper threshold level for the SHGC should be imposed for housing units located in mild climates or designed with large windows. Therefore, the building energy efficiency code of South Korea, which requires threshold values only for window *U*-factor should be improved to consider threshold levels for SHGC values.

Figs. 10 and 11 provide for Inchon and Ulsan the percentage reduction in annual total source energy savings use when windows are placed using typical distribution along the four orientations with WWR values of 45% (158.8 ft^2, 14.8 m^2), 15% (52.8 ft^2, 4.9 m^2), and 10% (29.3 ft^2, 2.7 m^2) in the south, north, and east and west walls, respectively. When the housing unit is located in Inchon as shown in Fig. 10, the percentage reduction in energy use attributed to glazing types #5 and #6 is almost zero indicating that these glazing types provide the same performance as the reference windows (i.e., SHGC=0 and *U*-factor=0), as shown in Fig. 10. The results of Fig. 10 also indicate that glazing type #3 is slightly more effective than glazing type #4 with an increase of total source energy use of about 10%. When the housing unit is located in Ulsan, however, windows with glazing types #5 and #6 cause an increase of over 10% in annual total source energy use compared to the reference case due to higher cooling loads attributed to solar heat gains.

It should be noted that the results illustrated in Figs. 4 through 10 clearly indicate that selecting any double-pane low-e glazing would provide better performance for windows in residential buildings than clear double-pane glazing, currently required by the Korean building energy efficiency code. To provide further insights into the performance of various glazing types, annual

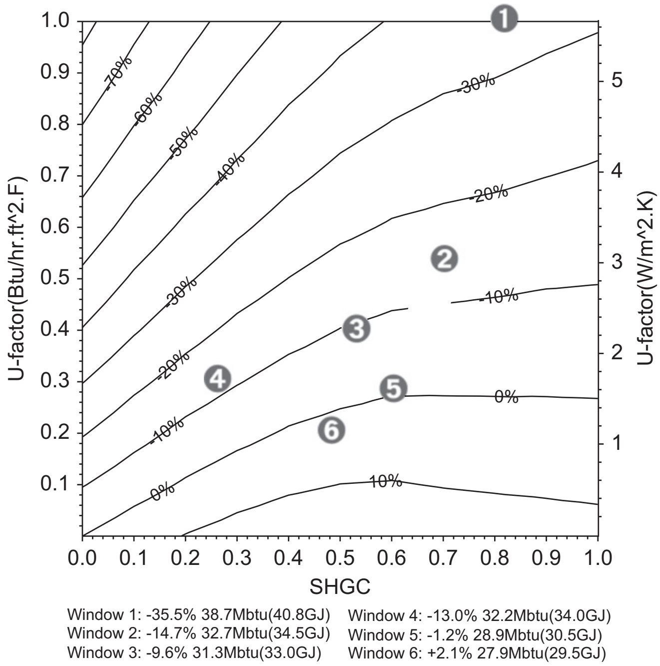

Fig. 10. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with typical window distribution located in Inchon.

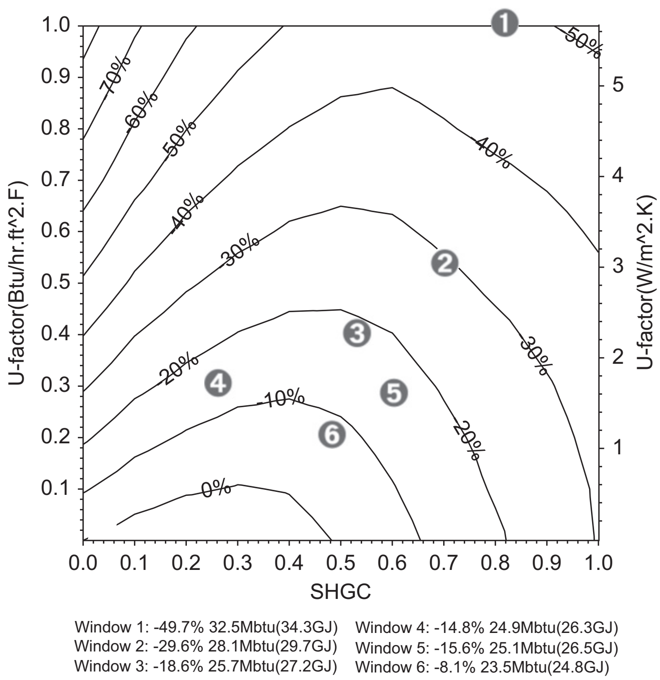

Fig. 11. Percentage reduction against baseline (SHGC 0 and *U*-factor 0) of annual source energy for a housing unit with typical window distribution located in Ulsan.

end-uses due to heating and cooling are estimated and evaluated as illustrated in Figs. 12 and 13.

Specifically, Figs. 12 and 13 summarize the percentage reduction in both annual electricity and natural gas uses associated with glazing types #2 through #6 listed in Table 4 compared to those obtained for single clear glazing (i.e., type #1) when windows are distributed uniformly in Inchon and Ulsan. The results of Fig. 12 indicate that both annual electricity and natural gas uses increase with the window size. However, no significant savings are obtained for electrical energy use compared to natural gas use especially for small windows (i.e., WWR=10%) due to lower impact on the housing unit cooling load. Glazing type #4 provides the highest electricity energy savings for both Inchon and Ulsan with 17% savings when the housing unit is located in Ulsan and has WWR=30%. Indeed, glazing type #4 has lower SHGC value resulting in lower solar heat gains and cooling loads compared to the triple glazing type #6. However, glazing type #4 provides the lowest gas savings compared to the other glazing types with only 3% savings against 23% for both glazing types #5 and #6 when the housing unit is located in Inchon. The results of Fig. 13 are similar to those of Fig. 12 indicating that the performance of the windows is not significantly affected by the distribution of the windows. In particular, Fig. 13 shows that savings of up to 12% of annual electricity use can be achieved when glazing type #4 is used instead of single clear glazing (i.e., type # 1) when the housing unit is located in Ulsan characterized by higher cooling degree-days than the climate of Inchon.

Tables 5a–c summarize the annual carbon dioxide (CO_2) gas emissions associated with the heating and cooling energy use for the prototypical housing unit designed with both uniformly or typically distributed windows and located in Inchon or Ulsan. The CO_2 gas emissions associated with electricity generation in South Korea is estimated to be 0.4524 kg CO_2/kWh (KESIS, 2009) and that associated with LNG is 0.05887 ton CO_2/MBtu (0.0558 ton CO_2/GJ) (KEMCO, 2010). The total amount of CO_2 gas emissions for a housing unit with single clear glazing (WWR 10%) located in Inchon is estimated to 2.0 ton per year. Tables 5a and b provide the percent reduction of carbon emissions for the housing unit with any window glazing type relative to that associated with single clear window (i.e., type #1). As indicated in Tables 5a and b, triple low-e glazing provides the highest reduction of CO_2 gas emissions for both Inchon and Ulsan with, respectively, 36% and 37% reductions when the housing unit has large windows uniformly distributed along the walls with WWR of 30%. With typical distribution of the windows, triple low-e glazing leads to 29% and 30% reduction in carbon emissions compared to single clear glazing when the housing unit is located, respectively, in Inchon and Ulsan as indicated in Table 5c.

In order to assess the cost-effectiveness of utilizing high performance windows for residential buildings in South Korea, a life cycle cost (LCC) analysis is performed for selected glazing types as listed in Table 4. The economic parameters and glazing prices are summarized in Table 6. The electricity and LNG rates are 0.1 $/kWh (Korea Price Information Corp, 2011) and 16.9 $/MBtu (0.016 $/MJ) (KOGAS, 2011). The LCC period and discount rate are set, respectively, to 30 years and 5%. The economical analysis results, summarized in Tables 7a–c, indicate that double low-e clear filled with argon gas (glazing type #4) is the most cost-effective with a reduction in LCC of 23% in Inchon and 19% in Ulsan. It should be noted that triple low-e window (glazing #5), which provides the highest savings in energy consumption and reduction in carbon emissions, is not cost-effective when the housing is located in Ulsan as any double-pane glazing as shown in Table 7b or even as compared to single clear glazing when the windows are typically distributed as indicated in Table 7c. Therefore and as found by a study in Hong Kong (Bojic and Yik, 2007), windows with triple low-e glazing are not cost-effective and thus are not recommended for housing units in South Korea.

4. Summary and conclusions

In this paper, a series of simulation energy analyses are performed to determine the impact of window features on the total energy use of prototypical residential buildings in South Korea.

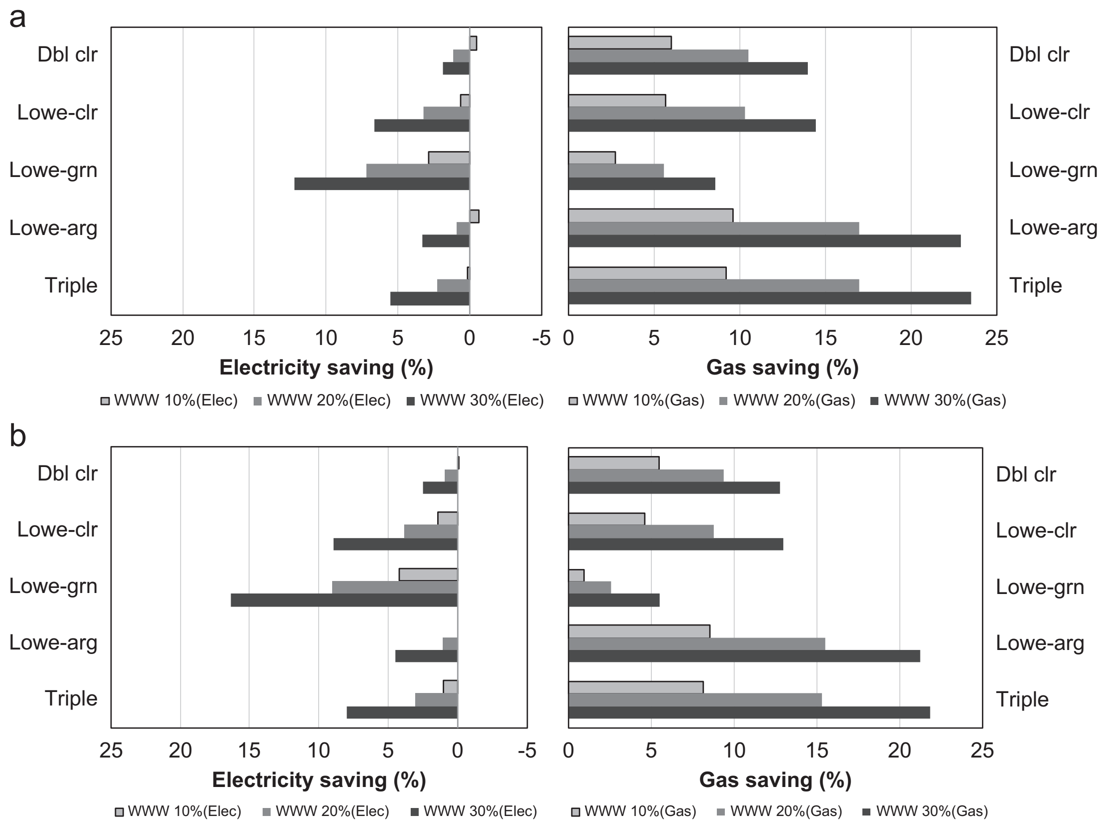

Fig. 12. (a) Annual electricity and gas saving percentage over single clear windows (Window #1, WWR 10%: electricity use 7.0 MBtu (7.4 GJ), gas use 28.7 MBtu (30.3 GJ); WWR 20%: electricity use 10.0 MBtu (10.5 GJ), gas use 31.3 MBtu (33.0 GJ); WWR 30%: electricity use 13.1 MBtu (13.8 GJ), gas use 34.7 MBtu (36.6 GJ)), for a housing unit with uniformly distributed windows located in Inchon. (b) Annual electricity and gas saving percentage over single clear windows (Window #1, WWR 10%: electricity use 10.9 MBtu (11.5 GJ), gas use 17.2 MBtu (18.2 GJ); WWR 20%: electricity use 15.6 MBtu (16.4 GJ), gas use 18.5 MBtu (19.5 GJ); WWR 30%: electricity use 21.4 MBtu (22.6 GJ), gas use 20.9 MBtu (22.1 GJ)), for a housing unit with uniformly distributed windows located in Ulsan.

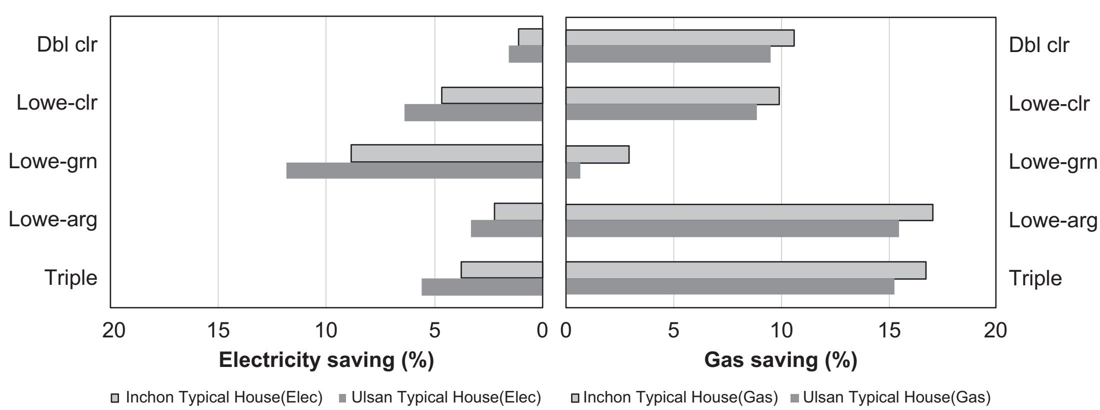

Fig. 13. Annual electricity and gas saving percentage (%) over single clear windows (Window #1, Inchon: electricity use 10.1 MBtu (10.6 GJ), gas use 28.6 MBtu (30.2 GJ); Ulsan: electricity use 15.9 MBtu (16.8 GJ), gas use 16.6 MBtu (17.5 GJ)) for a housing unit with typically distributed windows located in Ulsan.

In particular, the window-to-wall ratios as well as glazing *U*-factor and SHGC values are varied to determine the effect of window characteristics on heating, cooling, and total energy use of a typical housing unit located in Inchon and Ulsan, representative of two major climate zones in South Korea. The results of the energy simulation indicate that with the proper characteristics, windows can be energy neutral and even a positive energy source for residential buildings especially for the milder climate of Inchon. Moreover, it is found that upper threshold levels for the SHGC should be imposed especially for residential buildings located in mild climates or designed with large windows. Currently, the Korean building energy efficiency code specifies only *U*-values and does not have any requirements on SHGC values for glazing. In particular, it is clear that selecting any double-pane low-e glazing would provide better performance for windows in residential buildings than clear double-pane glazing, currently required by the Korean building energy efficiency code.

Based on a life-cycle cost analysis, it is found that windows with double low-e clear filled with argon gas are the most cost-effective for residential buildings in South Korea and should be required by the building energy efficiency code. While they provide the highest energy savings and carbon reductions, windows with triple low-e glazing are not cost-effective for housing units in South Korea.

As an extension of the analysis described in this paper, the thermal performance of dynamic glazing and advanced glazing

Table 5a
Annual heating/cooling CO_2 gas emissions and percent reduction relative to single clear window for a housing unit with uniformly distributed windows located in Inchon.

Window description	WWR 10% CO_2 (ton)	WWR 20% CO_2 (ton)	WWR 30% CO_2 (ton)	WWR 10% Reduction (%)	WWR 20% Reduction (%)	WWR 30% Reduction (%)
Single clear, vinyl frame	2.0	2.3	2.6			
Double clear, air, vinyl frame	1.8	1.9	2.1	10	16	20
Double low-e clear, air, vinyl frame	1.8	1.9	2.0	10	19	25
Double low-e green, air, vinyl frame	1.8	1.9	2.0	9	17	24
Double low-e clear, argon, vinyl frame	1.7	1.7	1.8	15	26	33
Triple low-e, air, vinyl frame	1.7	1.6	1.7	16	28	37

Table 5b
Annual heating/cooling CO_2 gas emissions and percent reduction relative to single clear window for a housing unit with uniformly distributed windows located in Ulsan.

Window description	WWR 10% CO_2 (ton)	WWR 20% CO_2 (ton)	WWR 30% CO_2 (ton)	WWR 10% Reduction (%)	WWR 20% Reduction (%)	WWR 30% Reduction (%)
Single clear, vinyl frame	1.5	1.8	2.2			
Double clear, air, vinyl frame	1.3	1.5	1.8	10	15	18
Double low-e clear, air, vinyl frame	1.3	1.4	1.6	11	20	26
Double low-e green, air, vinyl frame	1.3	1.4	1.5	11	21	29
Double low-e clear, argon, vinyl frame	1.3	1.3	1.5	16	25	30
Triple low-e, air, vinyl frame	1.2	1.3	1.4	17	29	36

Table 5c
Annual heating/cooling CO_2 gas emissions and percent reduction relative to single clear glazing for a housing unit with typically distributed windows located in Inchon and Ulsan.

Window description	Inchon CO_2 (ton)	Ulsan CO_2 (ton)	Inchon Reduction (%)	Ulsan Reduction (%)
Single clear, vinyl frame	2.13	1.68		
Double clear, air, vinyl frame	1.77	1.42	17	15
Double low-e clear, air, vinyl frame	1.72	1.32	19	21
Double low-e green, air, vinyl frame	1.82	1.34	15	20
Double low-e clear, argon, vinyl frame	1.55	1.25	27	26
Triple low-e, air, vinyl frame	1.51	1.18	29	30

Table 6
LCC analysis information and glazing price in Korea.

Electricity cost	0.1 $/kWh
LNG cost	16.9 $/MBtu (0.016 $/MJ)
Analyzed period	30 years
Discount rate	5%
Window description	***Price***
Single clear, vinyl frame	0.6 $\$/ft^2$ (6.6 $\$/m^2$)
Double clear, air, vinyl frame	2.9 $\$/ft^2$ (30.9 $\$/m^2$)
Double low-e clear, air, vinyl frame	4.1 $\$/ft^2$ (44.0 $\$/m^2$)
Double low-e green, air, vinyl frame	4.2 $\$/ft^2$ (44.8 $\$/m^2$)
Double low-e clear, argon, vinyl frame	5.7 $\$/ft^2$ (60.9 $\$/m^2$)
Triple low-e, air, vinyl frame	13.4 $\$/ft^2$ (143.8 $\$/m^2$)

Table 7a
LCC and saving percentage over single clear window for uniformly distributed windows in Inchon.

Window description	WWR 10% LCC ($)	WWR 20% LCC ($)	WWR 30% LCC ($)	WWR 10% Saving (%)	WWR 20% Saving (%)	WWR 30% Saving (%)
Single clear, vinyl frame	13,743	15,635	17,878			
Double clear, air, vinyl frame	12,646	13,594	15,037	8	13	16
Double low-e clear, air, vinyl frame	12,744	13,587	14,819	7	13	17
Double low-e green, air, vinyl frame	13,050	14,151	15,347	5	9	14
Double low-e clear, argon, vinyl frame	12,198	12,729	13,680	11	19	23
Triple low-e, air, vinyl frame	13,108	14,435	16,119	5	8	10

Table 7b
LCC saving percentage over single clear window for uniformly distributed windows in Ulsan.

Window description	WWR 10% LCC ($)	WWR 20% LCC ($)	WWR 30% LCC ($)	WWR 10% Saving (%)	WWR 20% Saving (%)	WWR 30% Saving (%)
Single clear, vinyl frame	9,888	11,629	14,124			
Double clear, air, vinyl frame	9,145	10,287	12,217	8	12	14
Double low-e clear, air, vinyl frame	9,206	10,202	11,762	7	12	17
Double low-e green, air, vinyl frame	9,394	10,411	11,763	5	10	17
Double low-e clear, argon, vinyl frame	8,871	9,801	11,453	10	16	19
Triple low-e, air, vinyl frame	9,764	11,457	13,740	1	1	3

Table 7c
LCC and saving percentage over single clear window for typically distributed windows in Inchon and Ulsan.

Window description	Inchon LCC ($)	Ulsan LCC ($)	Inchon Saving (%)	Ulsan Saving (%)
Single clear, vinyl frame	14,529	10,924	–	–
Double clear, air, vinyl frame	12,610	9,720	13	11
Double low-e clear, air, vinyl frame	12,662	9,528	13	13
Double low-e green, air, vinyl frame	13,639	9,986	6	9
Double low-e clear, argon, vinyl frame	11,766	9,266	19	15
Triple low-e, air, vinyl frame	13,655	10,968	6	−0.4

types such as electro-chromic glazing on building energy use could be analyzed to assess their impact and effectiveness in improving the energy efficiency of Korean residential buildings.

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